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Progress and challenges in utilization of palm oil biomass as fuel for decentralized electricity generation

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ABSTRACT

It has been broadly accepted worldwide that global warming, indeed, is the greatest threat of the time to the environment. Renewable energy (RE) is expected as a perfect solution to reduce global warming and to endorse sustainable development. Progressive release of greenhouse gases (GHG) from increasing energy-intensive industries has eventually caused human civilization to suffer. Realizing the exigency of reducing emissions and simultaneously catering to needs of industries, researchers foresee the RE as the perfect entrant to overcome these challenges. RE provides an effective option for the provision of energy services from the technical point of view while biomass, a major source of energy in the world until before industrialization when fossil fuels become dominant, appears an important renewable source of energy and researches have proven from time to time its viability for large-scale production. Being a widely spread source, biomass offers the execution of decentralized electricity generation gaining importance in liberalized electricity markets. The decentralized power is characterized by generation of electricity nearer to the demand centers, meeting the local energy needs. Researchers envisaged an increasing decentralization of power supply, expected to make a particular contribution to climate protection. This article investigates the progress and challenges for decentralized electricity generation by palm oil biomass according to the overall concept of sustainable development.

Contents

1. Introduction and background

Electricity is one of the driving forces of the economic development of societies. At the start of the 21st century, world faces significant energy challenges. The concept of sustainable development is evolved for a livable future where human needs are

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met while keeping the balance with nature. Driving the global energy system into a sustainable path has been emerged as a major concern and policy objective. Currently world's energy requirements are mostly fulfilled by fossil fuels. However, the overwhelming scientific evidence is that the unfettered use of fossil fuels is causing the world's climate to change, with potential catastrophic effect.

Electricity was originally generated at remote hydroelectric dams or by burning fossil fuels in the city centers, delivering electricity to nearby buildings and recycling the waste heat to make steam to heat the same buildings, while rural houses had no access to power. Over time, coal plants grew in size, facing pressure to locate far from population because of their pollution. Transmission wires carried the electricity many miles to users with a 10–15% loss [1]. Because it is not practical to transmit waste heat over long distances, the heat was vented. There was no good technology available for clean, local generation, so the wasted heat was a tradeoff for cleaner air in the cities. Eventually a huge grid was developed and the power industry built all-new generation in remote areas, far from users. All plants were specially designed and built on site, creating economies of scale. It cost less per unit of generation to build large plants than to build smaller plants. These conditions prevailed from 1910 through 1960, and everyone in the power industry and government came to assume that remote, central generation was optimal, that it would deliver power at the lowest cost versus other alternatives. Because of their high level of integration, are susceptible to disturbances in the supply chain. In the case of electricity especially, this supply paradigm is losing some of its appeal. Apart from vulnerability, centralized energy supply systems are losing its attractiveness due to a number of further annoying factors including the depletion of fossil fuels and their climate change impact, the insecurities affecting energy transportation infrastructure, and the desire of investors to minimize risks through the deployment of smaller-scale, modular generation and transmission systems [2].

2. Decentralized systems

Small-scale decentralized systems are emerging as a viable alternative as being less dependent upon centralized energy supply, and can sometimes use more than one energy source. On the basis of type of energy resources used, decentralized power is also classified as non-renewable and renewable. These classifications along with an overabundance of technological alternatives have made the prioritization process of decentralized power quite complicated for decision making. Establishing local generation and a local network may be cheaper, easier and faster than extending the central-station network to remote areas of modest load. The rural areas of many developing and emerging countries are unlikely ever to see the arrival of classical synchronized AC transmission lines. Decentralized local systems, including those using local resources of renewable energy such as wind, solar and biomass, appear much more feasible [3]. There is abundant literature, which has discussed various approaches that have been used to support decision making under such complex situations. The implementation of decentralized energy systems depends upon the extent of decentralization. The extent of decentralization also determines the condition for the system to be operated in either grid-connected (GC) or stand-alone (SA) mode. A number of articles have been presented for both success and failure narratives of implementation of SA as well as GC systems. But most of the articles were applied to isolated cases. A generalized approach to assess suitability of SA and GC systems at a given location, based on techno-economic financial-environmental feasibility does not find adequate coverage. Table 1 elaborates the important available technologies for decentralized power generation applicable in mode(s) and their features. Only biomass based technologies (cogeneration and gasification) are found to be more versatile towards both GC and SA modes and both can serve as combined heat and power (CHP) system.

A lot of studies have been made in last two decades to assess t and implement decentralized power systems. Recent researches on different aspects of decentralized power system are tabulated as Table 2 which clearly indicates a lack of adequate intension to above mentioned most promising technologies. In the mainstream media, these systems are increasingly associated with the benefits from virtually free, low-carbon and locally available renewable energy resources such as wind and solar power. But in the specific context of the built environment, the emphasis is on decentralized electricity generation associated with heat production. It is therefore important to realize the potential of biomass based technologies in GHG emission reduction in developed countries and their role in promoting sustainable rural development in developing countries. In this paper we called attention to palm oil biomass for decentralized electricity generation.

3. The origin and characteristics of oil palm

Oil palm botanically known as *Elaeis guineensis*, Jacq., is derived from the *Greek elaion* (oil), and the specific name of guineensis is an

Table 1
Comparative description of different decentralized technologies [2].

Technology	Features	Suitable mode
Co-generation	The average efficiency of co-generation systems is estimated to be 85%. The important co-generation technologies are bagasse co-generation, steam turbine combined heat, gas turbine combined heat	Both GC and SA
Biomass power	Producer gas is the consequence of modern use of biomass and its conversion to higher forms of gaseous fuel through the process of gasification. For small-scale applications, biomass requirement range from about 5 kg/h up to about 500 kg/h	Both GC and SA
Small and mini-hydro power	The small and mini-hydro power generation systems are environmentally benign as it is run of the river technology where the river flow is not impeded; as a result the river flooding problem is eliminated. The system is classified as small-hydro if the system size varies between 2.5 and 25 MW, mini-hydro typically falls below 2 MW, micro-hydro schemes fall below 500 kW and pico-hydro below 10 kW capacity	SA
Solar PV power	Efficiency of commercially available solar PV varies between 7 and 17%. Because of its high initial investment, cost of generation per kWh becomes high making it unaffordable	SA
Biogas	The gas that is produced through anaerobic digestion of biomass and other wastes like vegetable residues, animal dung, etc. is called biogas. Biogas generally is 60% methane and 40% carbon dioxide	SA
Wind power	Similar to PV systems wind energy systems are also site and season specific. Wind energy systems mostly operate in grid-connected mode, but only in a few villages isolated systems are operated to provide electricity for water pumping	GC

Table 2
Recent researches of decentralized electricity systems; Extracted from [4].

Author(s)	Year	Study domain/emphasis	Reference
Reddy et al.	1990	Choice of technology for quality energy services (cost comparison).	[5]
Siyambalapitiya et al.	1991	Importance of the pre-evaluation of techno-economic-social parameters of the grid-connected rural electrification systems.	[6]
Ramakumar et al.	1992	A knowledge based approach for the design of integrated renewable energy systems (IRES).	[7]
Joshi et al.	1992	Development of a linear mathematical model to optimize the energy mix of different energy source-end-use conversion devices to supply energy to villages (case study, India).	[8]
Ravindranath	1993	Biomass Gasification as environmentally sound technology for decentralizes electricity.	[9]
Ravindranath and Hall	1995	System configuration, operational details, and costing of a biogas unit. (case study, India)	[10]
Rana et al.	1998	Optimal RE mix for specific energy demand.	[11]
Sidrach-de-Cardona and Lopez	1998	Generalized model to evaluate energy losses and the performance of (a 2 kW)grid-connected photovoltaic system at different regions, climate conditions and irradiation (case study, Spain).	[12]
Gabler and Luther	1998	Development and validation of simulation and optimization model for a wind–solar hybrid SA system to optimize the design of converters and storage devices so as to minimize the energy payback time.	[13]
Bates and Wilshaw	1999	Status of solar PV power systems, governmental policies towards renewable and key market barriers for the successful and quick diffusion of solar PV power systems.	[14]
Ackermann et al.	1999	Simulation based validated economic optimization tool to evaluate different options for distributed generation, and improve power quality of an embedded wind generation system in weak grid conditions.	[15]
Meurer et al.	1999	Generation of measurement performance data of an autonomous SA hybrid renewable energy systems (RES) to optimize the energy output and operational reliability with the aid of simulation programs.	[16]
Vosen and Keller	1999	Optimization and simulation model for a SA solar powered battery-hydrogen hybrid system for fluctuating demand and supply scenarios using two storage algorithms for with or without prior knowledge about the future demand.	[17]
Gupta	2000	Policy approach in India for grid based RETs.	[18]
Stone et al.	2000	Investment, operational costs and impact of rural electrification project initiatives (case study, India).	[19]
Manolakos et al	2001	simulation based software tool for optimizing the design of a hybrid energy system consisting of wind and PV to supply electricity and water for a remote island village.	[20]
Kolhe et al.	2002	Economic viability of a stand-alone solar PV system along with a diesel-powered system.	[21]
Chakrabarti and Chakrabarti	2002	Feasibility study for solar energy based SPV stand-alone system based on socio-economic and environmental aspects (case study, India).	[22]
Martinot	2002	An extensive discussion on the policies, strategies and lessons learnt from the GEF (Global environmental Facility) project on the status of grid-based renewable energy systems in developing countries.	[23]
Bakos and Tsagas	2003	Techno-economic assessment for technical feasibility and economic viability of a hybrid solar/wind installation for residential electrification and heat (case study, Greece).	[24]
Kumar et al.	2003	Power costs and optimum size of a stand-alone biomass energy plant based on agricultural residues, whole forest residues, and residues of lumber activities (case study, Canada).	[25]
Kaldellis	2003	Financial analysis of grid-connected wind energy systems (of the entire Greek state).	[26]
Atikol and Guven	2003	Sizing of the grid-connected cogeneration systems based on electrical load and thermal load in textile industries (case study, Turkey).	[27]
Dasappa et al.	2003	Isolated biomass gasifiers being used to provide low temperature and high temperature thermal requirements of industries.	[28]
Ro and Rahman	2003	A computer model tested controller system to improve the system stability of fuel cell GC systems in power distribution network.	[29]
Santarelli et al.	2004	Design methodology of a stand-alone system, by integrating renewable energy systems, based on energy analysis, electricity management and hydrogen management (case study, Italy).	[30]
Hoogwijk et al.	2004	Some of the facts about geographical, technical and economic potential of wind across the globe.	[31]
Lindenberger et al.	2004	Analyses of modernization options for a local energy system, based on both demand reduction and supply-related measures as an extension of the optimization model called deco (dynamic energy, emission, and cost optimization).	[32]
Kishore et al.	2004	The potential role of biomass in global climate change mitigation and the extent of commercialization and mainstreaming of biomass energy technologies within the framework of clean development mechanism (CDM): a case study.	[33]
Beck and Martinot	2004	Policies and key barriers for diffusion of SA systems and GC systems like unfavorable pricing rules, private ownership, and lack of locational pricing leading to undervaluation of GC systems.	[34]
Dosiek and Pillay	2005	Design of a horizontal axis wind SA systems by simulation using MATLAB/SIMULINK.	[35]
Rabah	2005	Practical implementation of a stand-alone solar PV to improve the quality of life of poor (case study, Kenya).	[36]

Table 2 (*Continued*)

Author(s)	Year	Study domain/emphasis	Reference
Nakata et al.	2005	System configuration and operation of hybrid systems for the supply of heat and power based on a non-linear programming optimization model and METANet economic modeling system. (Japan).	[37]
Khan and Iqbal	2005	SA systems hybrid with other both renewable and nonrenewable sources of energy carriers as a potential solution to the problems of SA systems like low capacity factors, excess battery costs and limited capacity to store extra energy.(using HOMER software to optimize and arrive at the right combination of energy systems).	[38]
Pelet et al.	2005	Multi-objective evolutionary programming technique to rationalize the design of energy systems for remote locations.	[39]
Santarelli and Pellegrino	2005	Mathematical optimization model to minimize the total investment cost of hydrogen based stand-alone system to supply electricity to residential users, integrated with renewable energy systems like solar PV and micro-hydro.	[40]
Kamel and Dahl	2005	Economic assessment of hybrid solar–wind systems against the diesel using NREL's renewable energy simulation tool called HOMER (hybrid optimization model for electric renewables).	[41]
Jeong et al.	2005	A fuzzy logic algorithm as a strategy for effective load management resulting an improved resilience and system operation efficiency of a hybrid fuel-cell and battery stand-alone system.	[42]
Silveira	2005	The potential of CDM in promoting bio-energy technologies to promote sustainable development in developing countries.	[43]
Holland et al.	2006	Assessment of the critical factors for successful diffusion of standalone systems in rural regions.	[44]
Gulli	2006	Social-cost benefit analysis of stand-alone combined heat and power (CHP) systems based on both internal and external system costs.	[45]
Mahmoud and Ibrik	2006	Computer-based dynamic economic evaluation model with key economic efficiency indicators to assess three supply options namely solar PV, diesel generators in SA system and grid extension.	[46]
Hiremath et al.	2006	Review on decentralized energy planning models.	[47]
Jebaraj and Iniyan	2006	Reviews on decentralized energy models.	[48]
Ravindranath et al.	2006	Assessment of carbon abatement potential of bioenergy technologies (BETs) by comparison with fossil fuel alternatives.	[49]
Bernal-Agustin and Dufo-Lopez	2006	Economic analysis on the grid-connected Solar PV system (case study, Spain).	[50]
Faulin et al.	2006	Potential of RETs in generating local employment (case study, Spain).	[51]
Fernandez-Infantes et al.	2006	A computer-based decision support system to design the GC PV system based on electrical, environmental and economic considerations.	[52]
Zoulias and Lymberopoulos	2007	Simulation and optimization of replacement option of conventional technologies with hydrogen technologies, fuel cells in an existing PV-diesel operated in stand-alone mode by using HOMER tool.	[53]
Kasseris et al.	2007	Optimization model of the wind-fuel cell hybrid system for larger output under strict and lenient grid network restrictions.	[54]
Hiremath et al.	2007	Total potential, installed capacities of decentralized energy systems (case study, India).	[55]
Purohit and Michaelowa	2007	Feasibility of Bagasse cogeneration projects under CDM with a total CER potential up to 26 million.	[56].
Walker	2008	Assessment of the linkage between stand-alone systems and fuel poverty (case study, UK).	[57]
Purohit	2008	A detailed estimation of small hydro power (SHP) potential in India under CDM.	[58]
Adhikari et al.	2008	An overview of CDM portfolio in Thailand by cataloguing potential, opportunities and barriers for executing decentralized sustainable renewable energy projects in the context of CDM.	[59]
Lybaek	2008	Assessment of market opportunities in Asian countries for SA biomass CHP. (case study, Thailand).	[60]
Salas and Olías	2009	Extensive analysis of all the electrical parameters of grid-connected solar inverters for applications below 10 kW.	[61]
Carlos and Khang	2009	A generalized framework to assess the factors affecting the successful completion of grid-connected biomass energy projects validated with real world data of power plants. (Thailand).	[62]
Doukas and Karakosta	2009	The economic, environmental and sustainable benefits as well as removal of barriers for satisfactory dissemination of important RES technologies.	[63]

indication of its origin from the equatorial Guinea coast [64,65]. Oil palm, a monocotyledon belonging to tropical perennial plant [66], is a monoecious crop as it bears both male and female flowers on the same tree. It comprises two species of the Arecaceae (palmae family) [67,68] and its single-stemmed mature trees can grow to a height of 20–30 m [69]. The fleshy fruits grow in large female bunches, each weighing as much as 10–40 kg, containing up to 1000–3000 fruitlets per bunch [69,70]

3.1. West Africa

The oil palm is a native of West Africa. It flourishes in the humid tropics in groves of varying density, mainly in the coastal belt between 10° north latitude and 10° south latitude. It is also found up to 20° south latitude in Central and East Africa and Madagascar in isolated localities with a suitable rainfall. It grows on relatively open ground and, therefore, originally spread along the banks of rivers and later on land cleared by humans for long-fallow cultivation [71,72]. West Africa is the classic region of smallholder production, both of food and export crops. The oil palm, which has been both, flourishes in natural association with yam and cassava cultivation throughout the wetter parts of the region. In eastern Nigeria, which Hartley [73] called "the greatest grove area of Africa," densities of 200 palms per hectare (ha) were common in the late 1940s, and densities of more than 300 palms per ha were not unknown. A number of state-run estates were established

under French influence in the Ivory Coast after 1960. By 1981 these estates covered a total of 52,000 ha, with a further 33,000 ha planted with oil palms in the surrounding villages [73] in the kingdom of Dahomey and in settlements established by the Krobo people near Accra, some deliberate plantings may have been made as the palm oil export trade developed from the 1830s [74,75]. However, as Reid [76] has noted, the word plantation was often used by contemporary European observers to mean a food farm on which oil palms happened to be growing. Moreover, although in Dahomey descriptions exist of seedlings being transplanted from the bush onto areas cleared for farming by slaves, this does not mean that the practice was universal. In any event, palm oil exports from Dahomey were much smaller than from the Niger Delta, where oil palms were planted deliberately in swampy regions outside their natural habitat, but where the bulk of production was carried out using natural groves. In the 1840s, Dahomey and the Niger Delta exported approximately 1000 and 13,000 tonnes per annum respectively; by the 1880s these totals had risen to 5000 and 20,000 [74].

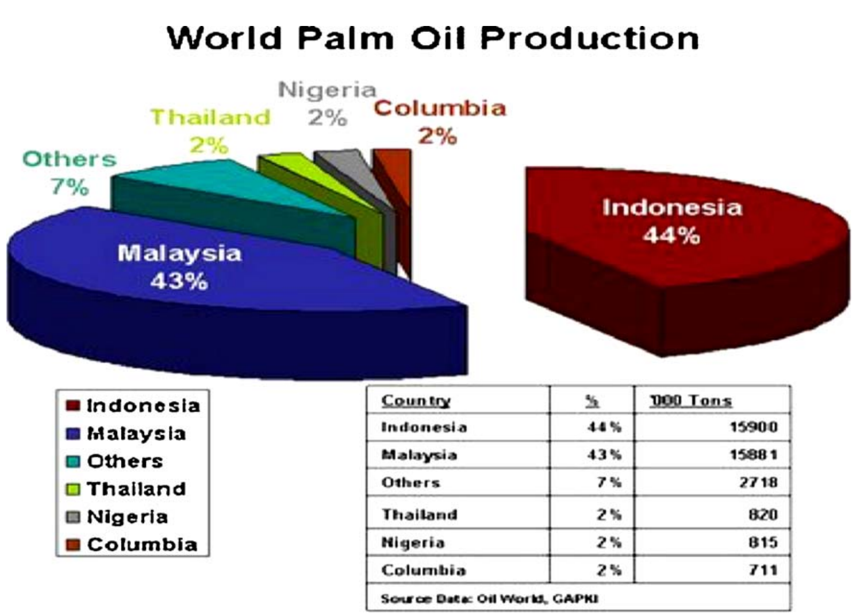
In late nineteenth century, a number of experimental oil palm plantations were created by Europeans in West and west-central Africa. In 1907 William Lever sought large-scale land concessions in the British West African colonies in order to produce palm oil for his Lancashire soap mills. A number of state-run estates were established under French influence in the Ivory Coast after 1960. By 1981 these estates covered a total of 52,000 ha, with a further 33,000 ha planted with oil palms in the surrounding villages [73]. Yet even this development was relatively modest in scale, as shown in unpublished data from Nigeria, West Africa's largest producer of palm oil. The area of wild palm groves, only partly harvested, was estimated at 2,400,000 ha, whereas there were 72,000 ha of estate plantations and another 97,000 ha of smallholder plantations [72].

3.2. Central Africa

In the late nineteenth century, both the German colonizers of Kamerun and the Belgian rulers of the Congo were keenly interested in applying European farming and processing techniques to the palm oil industry. But German botanical and mechanical trials were cut short by World War I, following which the German territories in Africa were divided between the French and the British. In the Congo, however, Lever's initial land- and produce-buying concessions (granted in 1911) proved to be the foundation for a long process of experimentation, which eventually revolutionized the palm oil industry worldwide. New planting materials led to dramatic increases in yields, thus cutting the cost of production; and improved machinery led to high oil quality at a competitive price. Alongside developments in European and American food-processing techniques, the Congo innovations paved the way for the entry of palm oil into Western diets. Congo was not the state that gained the most. Its oil palm plantations did expand from 52,000 ha in 1938 to 93,000 in 1945 and 147,000 in 1958, with a further 98,000 ha under smallholder cultivation by the end of that period. But political unrest following independence in 1960 led to stagnation and decline in the industry. at a national level, the research effort was decimated, and new planting was very limited after 1960, in marked contrast to developments at the same time in Southeast Asia [72,73].

3.3. Southeast Asia

The oil palm was first introduced to Southeast Asia in 1848, when four seedlings, originating from West Africa, were planted in the botanical gardens at Buitenzorg (now Bogor) in Java [73]. But this introduction did not lead to a plantation industry for some time, although offspring of the palms were used as ornamentals by tobacco planters. By 1919 more than 6000 ha had been planted in Sumatra (Indonesia), rising to 32,000 in 1925, by which time 3400 ha had come under cultivation in Malaya. Over the next five years, a further 17,000 ha were planted in Malaya, while the Sumatran area doubled [72]. In Sumatra hung fire for some time after 1945, meanwhile, developments in Malaysia were more rapid, especially after 1960, when the replanting of old rubber estates with oil palms was stimulated by FELDA's smallholder schemes. Malaysia is the world's second largest producer of palm oil (in years 2006–2009), with 15.88 million tonnes or 43% of the total world supply as shown in Fig. 1. In 2007, productive oil palm plantations in Malaysia were 4.3 million ha and by the year 2030, the annual production is predicted to be further strengthened to 50



Country	%	'000 Tons
Indonesia	44%	15900
Malaysia	43%	15881
Others	7%	2718
Thailand	2%	820
Nigeria	2%	815
Columbia	2%	711
Source Data: Oil World, GAPKI		

Fig. 1. World producers of oil palm in 2009 [78].

million tones [77]. In Indonesia, almost 2.7 million ha of coconuts and 3.6 million ha of oil palms were grown in 2005. Like Malaysia, the country is also strengthening its oil palm production with the increasing worldwide demand for biodiesel derived from palm oils. It is keen to establish the world's largest oil palm plantation on 1.8 million ha of land in Kalimantan on the island of Borneo.

3.4. Latin America

A distinct species of the oil palm, Elaeis oleifera (also known as Elaeis melanococca), is indigenous to Latin America. Since the late 1960s, this variety has gained an increasing interest because its oil has a high iodine value and unsaturated fatty acid content, making it especially suitable for food use. *E. guineensis* seeds were introduced to Central America by the United Fruit Company, which brought seeds from Sierra Leone to Guatemala in 1920, and from Malaysia to Panama in 1926 and Honduras in 1927. Other introductions from Java and the Belgian Congo followed, but the first commercial planting of 250 ha took place only in Guatemala in 1940. By 1992 the total area planted to *E. guineensis* in Latin America had grown to 390,000 ha – still a small fraction of the area in Africa or Southeast Asia [72].

4. The rapid propagation and development of palm oil industries

The strong global demand for oils and fats has caused a rapid growth of the oil palm industry in the Asian region, leading to the conversion of large areas of land to oil palm production. Malaysia and Indonesia produce over 87% of the total world output of palm oil [79]. Production in Indonesia has now reached 3 million ha of which 33% is smallholder production and 19% government owned estates; the remainder being privately owned companies. In Malaysia, around 3.7 million ha are planted (51% of which is smallholder or government owned) and which produce 11.9 million tonnes of palm oil per annum. Palm oil and palm oil products are key exports for these countries, with 14.7 million tones exported annually ($4500 million) from Malaysia [80]. Fig. 2 shows the comparison and trend of palm oil production in both leading countries.

The growing affluence of India and China, the world's top two importing nations, will increase demand of edible vegetable oils. In the US, a recent wave of dietary focus on the trans-fat issues has led to increased consumption. In addition to being less expensive, palm oil is semi-solid at room temperature, making it ideal for baking and food production. Many food manufacturers are trying to find alternatives to trans-fat, partially hydrogenated oils, which contribute to heart disease and other medical problems. Although, palm oil is not without its own contribution to heart disease, the focus on the trans-fat issue has resulted in palm oil being considered more healthful than some other fats. The other major factor of palm production is its role in sustainable energy campaigns around the globe. European countries have promoted the use of palm oil by injecting hundreds of millions of dollars into national subsidies towards bio-diesel. Europe is now a leading importer of palm oil. Through the subsidizing of biofuels, European governments have accelerated the demand for palm oil in Europe, and as a consequence have accelerated the conversion of large areas of rainforest in South East Asia. Palm oil plantations are often expanded by clearing existing forest land and draining peat swamps. Many economists predict it will be the leading internationally traded edible oil by the year 2012 [79]. The palm oil industry is increasingly seeking to ensure sustainability in production and a viable future for the whole industry

4.1. Palm oil biomass

Palm oil is the second most traded vegetable oil crop in the world, after soy, and over 90% of the world's palm oil exports are produced in Malaysia and Indonesia [67,81]. Oil palm is the highest yielding oil crop, producing on average about 4–5 tonnes of oil/ha/year, about 10 times the yield of soybean oil [67]. Palm oil is mostly used in the manufacture of food products; however, palm oil is now starting to be used as an ingredient in bio-diesel and as a fuel for electricity generation. This is a new market for palm oil having potential to increase global demand for this commodity. Oil palm tree (tenera variety) starts bearing fruits after 30 months of field planting and remains continue to be productive for the next 20–30 years; thus ensuring a consistent supply of oils [69]. Thus, oil palm can act as a net source of useful energy [82]. For example, in Malaysia, from merely 54,000 ha in the early 1960s, the oil palm plantation area has gradually increased to 1.8, 3.5, 3.8, 3.87, 4.2 and 4.3 million ha in 1990, 2001, 2003, 2004, 2005 and 2007 respectively [83,84], representing 56% of the total agricultural land and 11.75% of the country's total land area [64]. With the growth of palm oil production in Malaysia, the amount of residues generated also shows a corresponding increase. The type of biomass produced from oil palm industry includes empty fruit bunch (EFB), fiber, shell, wet shell, palm kernel, fronds and trunks. Table 3 also summarizes the types and quantity of oil palm biomass generated per year (based on 2005 data) in Malaysia to present a depiction of energy potential of palm oil boimass.

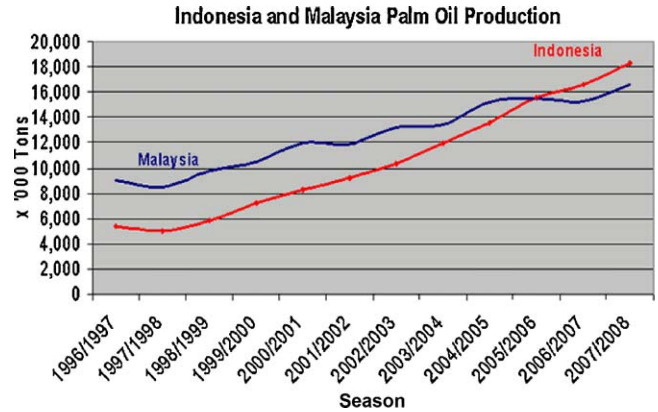


Fig. 2. Comparison and trend of Palm oil production in Indonesia and Malaysia 1996–2008 (adopted from [79]).

4.2. Energy and biomass

Energy is an integral part of society and plays a critical role in its socio-economic development by raising the living standard. The state of economic development of any region can be evaluated from the pattern and consumption quality of its energy. As the economy grows, the energy demand increases and the consumption pattern vary with the source and availability of its energy, conversion loss and end use efficiency [87,88].

During different stages of development, societies have experimented with various sources of energy ranging from wood, coal, oil

Table 3
Oil palm biomass collected in Malaysia in 2005 and their energy potential [67,85].

Biomass component	Quantity available (million tonnes)	Calorific value (kJ/kg)	Potential energy generation Potential (Mtoe)
Empty fruit brunches	17.00 [86]	18,838	7.65
Shell	5.92	20,108	2.84
Fiber	9.60	19,068	4.37
Palm kernel	2.11	18,900	0.95
Fronds and trunks	21.10	–	–
Total	55.73	–	15.81

Table 4
Recent researches of Bio-energy technologies.

Author(s)	Year	Study domain/emphasis	Reference
Chen et al.	2010	Potential to develop various renewable energies, such as solar energy, biomass energy, wind power, geothermal energy, hydropower in Taiwan and the review of the achievements, polices and future plans in this area.	[92]
Kumar et al.	2010	Review of the availability, current status, major achievements and future potentials of renewable energy options including biomass, hydropower, wind energy, solar energy and geothermal energy .in India.	[93]
Sheikh	2010	Review of RE supply options; solar energy, wind energy, microhydel power, biogas and geothermal energy in Pakistan.	[94]
Iglinski et al.	2010	Current status and future objectives of wind power, solar power and biomass power in the Kujawsko-Pomorskie Voivodeship (Poland).	[95]
Asif	2009	Renewable energy-based electricity supply options such as marco-/micro-hydro, Biomass in the form of crop residues and animal waste and municipal solid waste, small wind electric generators and photovoltaics in Pakistan.	[96]
Ghobadian et al.	2009	Potential and feasibility to develop various renewable energies, such as solar energy, biomass and biogass energy, wind power and geothermal energy in Iran.	[97]
Chen et al.	2009	Feasibility of densified solid biofuels technology for utilizing agro-residues in China.	[98]
Himri et al.	2009	A review of the use of renewable energy situation and future objectives in Algeria.	[99]
Paska et al.	2009	An overview on the present state and perspectives of using renewable energy sources including hydropower, solar energy, wind energy biomass and biogas in Poland.	[100]
Mirza et al.	2008	Potential of biomass for energy generation in Pakistan.	[87]
Nouni et al.	2008	Renewable energy-based decentralized electricity supply options such as micro-hydro, dual fuel biomass gasifier systems, small wind electric generators and photovoltaics in India.	[101]
Bilgen et al.	2008	Renewable energy potential and utilization in Turkey and Global warming issues.	[102]
Rofiqul Islam et al.	2008	Review of RE supply options; solar energy, wind energy, hydro power, biogas and tidal energy in Bangladesh with concluding remarks There is no way other than taking bio and solar energy for reducing environmental degradation.''	[103]
Sumathi et al.	2008	Potential of oil palm as bio-diesel crop and waste stream as a source to produce vast amounts of bio-gas and other values added products.	[104]
Omer	2007	Present status of rural energy recourses including solar energy biomass and biogas energy in Sudan.	[105]
Zeng et al.	2007	An overview on the technology status, potential and the future research and development of straw in the biomass energy portfolio in China.	[106]
Hossain and Bad	2007	Biomass energy potential for the planning small- to medium-scale biomass-to-electricity plants in Bangladesh.	[107]
Bugaje	2006	Review of RE scenario in Africa using South Africa, Egypt, Nigeria and Mali as case studies with solar energy and wood biomass as major recourses.	[108]
Chang et al.	2003	An overview on the research and development of renewable energy, such as solar, biomass, geothermal, ocean and wind energy in China.	[109]

and petroleum to nuclear power. In recent years, public awareness and political concerns over environmental issues and energy security have led to the promotion of renewable energy resources. Biomass is one such resource that could play a significant role in a more diverse and sustainable energy mix. The energy obtained from biomass is a form of renewable energy and, in principle, utilization of this energy does not add ''new'' carbon dioxide, a major greenhouse gas, to the atmosphere, in contrast to fossil fuels. Biomass has been used as an energy source for thousands of years, ever since humans started burning wood to cook food or to keep them warm. As per an estimate, globally photosynthesis produces some 220 billion tonnes of dry biomass each year with 1% conversion efficiency [77,87–90].

4.3. Bio-power technologies

Bio-power, or biomass power, is the use of biomass to generate electricity. There are six major types of bio-power systems: direct-fired, co-firing, gasification, pyrolysis, anaerobic digestion and small, modular systems. Most of the bio-power plants use direct-fired systems. In addition, gas and liquid fuels can be produced from biomass through pyrolysis. In pyrolysis biomass is heated in the absence of oxygen. The biomass then turns into a liquid called pyrolysis oil, which burns like petroleum to generate electricity. Several bio-power technologies can be installed in small, modular systems which can generates electricity at a capacity of 5 MW or less [91]. Bridgwater et al. [90] presented a comparison of pyrolysis, gasification and direct combustion for electricity generation from wood chip feedstock and concluded that fast pyrolysis system has great potential to generate electricity at a profit in the long term, and at a lower cost than any other biomass to electricity system at small scale. A lot of studies have been made by researchers for the environmental and economic feasibilities of RE from biomass for different countries. Table 4 shows these recent researches. Most of these researches focused on alternative fuels as RE source and no remarkable work have been done for the direct electricity generation option from biomass.

Recently, Buragohain et al. [110] highlighted the technical and economical issues related to decentralized power generation in India using biomass gasification and present their analysis for both fixed bed and fluidized bed gasification with pre-and post-process treatment. The study suggests that the downdraft gasifier design, being well developed and demonstrated, is the most feasible technology for wood biomass to energy conversion (Fig. 3a–c). Formerly Lora and Andrade [111] demonstrated available technologies for electricity generation out of biomass for different power ranges and concluded that biomass energy technologies having the high and medium technological maturity and economic feasibility are the steam cycle, gasification with internal combustion and Stirling engine and biodiesel/internal combustion engines. For small power systems (5–200 kW) the situation is critical as they are not available technologies with high technological maturity

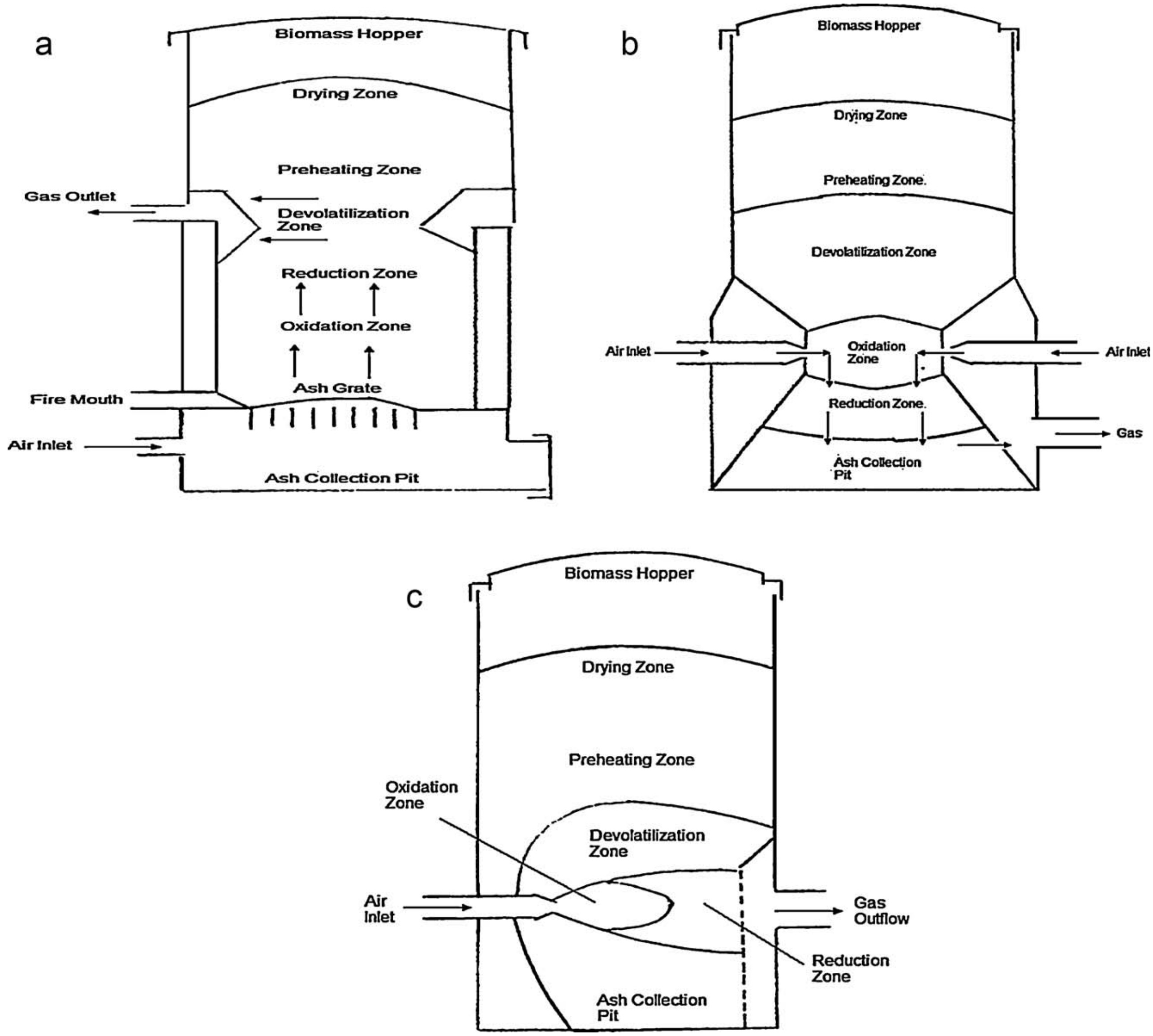


Fig. 3. (a) Schematic of an updraft biomass gasifier (adopted from [110]). (b) Schematic of a downdraft biomass gasifier (adopted from [110]). (c) Schematic of a cross-draft biomass gasifier (adopted from [110]).

and economical feasibility. Extensive research is still needed to find optimal biomass to energy conversion flow sheet with minimum waste generation and valuable by-products.

4.4. Bio-power using palm oil biomass: current trend and major challenges

In palm waste power generation industry, electricity in generated mostly by direct combustion of biomass with lower efficiency, however, there is a major shift in the technology for the last five years. Previously, boiler ash removal was manual with formation of clinkers along with ash. But now, the ash removal is automatic, resulting in increased efficiency. In addition, these days, EFB is also used as a boiler fuel along with fiber and shell. Some equipment suppliers are even trying to use 100% EFB for their boilers and they are likely to succeed soon [112]. Palm oil industries in Malaysia, Indonesia and Thailand have good potential for high pressure modern power plants and the annual power generation potential is about 8000, 5000 and 500 GWh, respectively [113]. Biomass power generation market in Africa is almost unexplored and the potential is huge. Palm oil industries often use very old fiber fired steam boilers to produce steam to meet the steam demand for the palm oil production mill. The electricity required is met by the diesel gensets. EFB are mainly burnt in the mill itself and the ash is used by soap manufacturers [114]. However, from the present plans of governments in East Asian countries, it is foreseeable that large amount of land, water and man-power resources will be devoted to bioenergy programs.

Available biomasses to power conversion technologies are equally applicable for all types of feedstock including Plam Oil Biomass. There have also been many studies performed in recent decades to estimate the future demand and supply of biopower. Overall, the world's bioenergy potential seems to be large enough to meet the global energy demand in 2050 [115]. Shifting the energy mix from fossil fuels to renewables can now in most cases be done using best practices and existing technologies. However, the shift in the energy mix requires much more investment in infrastructure, equipment and in R&D in case of palm oil biomass. Moreover, a prerequisite for achieving bioenergy's substantially, high potential in all regions is replacing current inefficient and low-intensive management systems with best practices and technologies.

5. Conclusion

In addition to economic gains in cost reduction of imported fossil fuels, development of bioenergy will result in energy security for the East Asian countries by diversifying the energy supply. Generating decentralized electricity, such as biopower through Biomass Gasifier Technology could be a boon to the people in remote areas. This would help transform the entire economic activities and life style of the people. A large part of rural population would be able to use the energy for various basic needs. Countries like Malaysia, Indonesia, Thailand and Nigeria have great potential to generate decentralized electricity from palm oil biomass. Extensive research is still needed to find optimal Palm oil biomass to energy conversion flow sheet with minimum waste generation and valuable by-products.

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